

# Is Planck's Constant $h$ a "Quantum" Constant?

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## Abstract

One should not confuse a physical constant with a theory which incorporates the constant. Planck's constant  $h$  can appear in classical or quantum theories.

Physics students and sometimes physics teachers have a mistaken idea about the role of Planck's constant in physics. Contrary to the impression of many, the presence of Planck's constant  $h$  in the formula for some physically observed phenomenon does not necessarily indicate whether the formula was derived from a classical or from a quantum theory. It seems important to make a distinction between *physical constants* and *physical theories*.

*Physical constants* are numbers obtained from experimental measurements. Examples are  $g=9.8\text{m/sec}^2$  for the acceleration due to gravity near the surface of the earth,  $c=3.0\times 10^8\text{m/sec}$  for the speed of light in vacuum,  $e=1.6\times 10^{-19}\text{C}$  for the smallest elementary charge,  $a_S=7.6\times 10^{-16}\text{J}/(\text{m}^3\text{K}^4)$  for Stefan's radiation constant,  $h=6.6\times 10^{-34}\text{J sec}$  for Planck's constant, and  $v_{air}=344\text{m/sec}$  for the speed of sound in air at normal pressure and density. Some of these constants, such as  $c$ ,  $e$ ,  $a_S$ , and  $h$ , are regarded as universal, whereas others, such as  $g$  and  $v_{air}$ , depend upon very specific experimental circumstances.

*Physical Theories* are sets of rules for describing physical phenomena; these theories may or may not incorporate various physical constants. Thus, for example, a Newtonian theory of particle motion near the surface of the earth which does incorporate gravity would treat  $mg$  as a downward force on a mass  $m$  and would give vertical free-particle motion as

$$y = y_0 + v_0t - (1/2)gt^2 \quad (1)$$

(measuring displacement vertically upwards). On the other hand, a classical mechanical theory which did *not* incorporate gravity might give the motion as

$$y = y_0 + v_0t \quad (2)$$

omitting the physical constant  $g$ , and so giving a less accurate description of the phenomenon. Equation (2) becomes accurate only at high initial velocities and short times when the effects associated with the physical constant  $g$  can be ignored. Finally, the physical situation can also be described by general relativity, in which case the physical constant  $g$  would again enter the theory; however, in this case, the constant  $g$  would be related to the curvature of spacetime. Within the appropriate approximation, the general relativistic analysis would lead back to Eq. (1). In this example, both Newtonian gravity and general relativity incorporate the physical constant  $g$ , but incorporate it in very different fashions. The mere presence of the physical constant  $g$  in Eq. (1) does not indicate which theory was used as the starting point in the physical analysis.

An analogous situation holds for the physical constant  $h$ , Planck's constant. *Traditional* classical mechanics and *traditional* classical electrodynamics do not include the physical constant  $h$ , just as the classical description above which omitted gravity does not include  $g$ . Accordingly, these theories give accurate descriptions of phenomena only when the constants  $h$  or  $g$  play no significant role. However, there are several theories which do include  $h$ , and the final formula which describes some phenomenon does not indicate which theory was used as the starting point for the analysis. Among the physical theories which include Planck's constant  $h$  are nonrelativistic quantum mechanics, quantum electrodynamics, and classical electrodynamics with classical electromagnetic zero-point radiation (stochastic electrodynamics).[1] Of course, quantum mechanics and quantum electrodynamics are widely-known successful theories which are taught in universities. However, classical electrodynamics with classical electromagnetic zero-point radiation is a mathematically-consistent classical theory which incorporates Planck's constant  $h$  as the scale constant of the Lorentz-invariant spectrum of random classical radiation which is chosen as the homogeneous boundary condition on Maxwell's equations. The zero-point radiation in this theory is described in the same terms as the thermal radiation of nineteenth century physics. There are no discrete (quantum) aspects of energy or momentum in this classical theory. In *traditional* classical electrodynamics, the homogeneous solution of Maxwell's equations is taken to vanish so that there is no zero-point radiation, and therefore Planck's constant  $h$  simply does not enter the theory at all.[2] Classical electrodynamics with classical electromagnetic zero-point radiation has been shown to give the same results as nonrelativistic quantum mechanics and quantum electrodynamics for free electromagnetic fields and for linear mechanical systems weakly coupled to radiation.[3] The classical theory can account for Casimir forces between macroscopic objects, van der Waals forces between molecules, oscillator specific heats, specific heats of solids, diamagnetism, and the thermal effects of acceleration through the vacuum, giving results identical to those from quantum theories.[4] Also, simulation work indicates that this classical theory can account for the Schroedinger ground state of hydrogen.[5] The limits of the theory are still being explored.[6] Most importantly, the appearance of Planck's constant  $h$  in the final formula for these phenomena

does not indicate whether the starting theory was a classical or a quantum theory.

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- [2] H. A. Lorentz, *The Theory of Electrons* (Dover, New York, 1952). This is a republication of the 2nd edition of 1915. Note 6, p. 240 gives Lorentz's explicit assumption on the boundary conditions on Maxwell's equations.
- [3] T. H. Boyer, "General connection between random electrodynamics and quantum electrodynamics for free electromagnetic fields and for dipole oscillator systems," Phys. Rev. D **11**, 809-830 (1975); "Random electrodynamics: The theory of classical electrodynamics with classical electromagnetic zero-point radiation," Phys. Rev. D **11**, 790-808 (1975).
- [4] L. de la Pena and A. M. Cetto, *The Quantum Dice - An Introduction to Stochastic Electrodynamics* (Kluwer Academic, Dordrecht, 1996).
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